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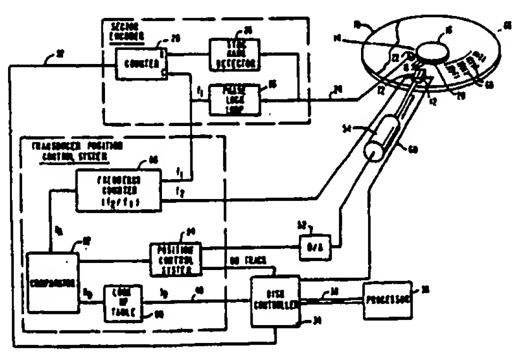
(54) **A record disk bearing a servo pattern and record disk apparatus comprising such a record disk.**

(57) A servo pattern (70) of detectable marks is so disposed on a record disk (66) that when the disk is rotated past a sensor device (72) for sensing the marks, there is a plurality of nested (e.g. substantially concentric) paths along which the rate of sensing the marks is individual to each path whereby it is possible to define a record track (68) on the disk by reference to a selected one of the paths.

The servo pattern (70) does not interfere with or use any of the recording capacity of the record medium (74) on the disk. The servo pattern is sensed by a sensor (72) different from any transducer (12) used to access the record medium. The record medium can be a conventional magnetic layer and the servo pattern can be formed of optically reflective or non-reflective spots overlying or underlying the magnetic record medium.

The sensor (72) is mounted for common radial movement with the transducer (12). As the record disk spins, the sensor produces an output signal from which is derived a mark sensing rate signal. Each record track (68) is defined by an individual mark sensing rate. A servo control system positions the transducer (12) so that the mark sensing rate is maintained at the rate defining a desired record track (68).



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A RECORD DISK BEARING A SERVO PATTERN AND RECORD DISK APPARATUS COMPRISING SUCH A RECORD DISK

This invention relates to a record disk bearing a servo pattern and record apparatus comprising such a record disk.

It is generally desirable to increase as much as practicable the amount of data which can be stored on a record disk. Data is generally stored on a disk along concentric circular tracks. Obviously, it is desirable to fit as many tracks as possible on a disk surface, which means that the tracks should be as narrow as practicable and as close together as practicable. However, it is also necessary to position a transducer over the middle of any desired track and to keep it there during rotation of the disk while data is written into the track or read from the track. As the tracks become ever smaller in width and are spaced closer and closer together, it becomes ever more difficult to correctly position the read and/or write transducer. In reality it is the ability to reliably position a transducer over the center of a desired track and to keep it so positioned during rotation of the disk which limits the density of the recording tracks.

With magnetic record disks, typically an open loop positioning system with no feedback control is used to coarse position either one or an array of read/write transducers over a desired track. With flexible magnetic record disks, this is often the only positioning system for the transducer. With hard magnetic record disks, coarse positioning is generally followed by fine positioning using a positioning system with feedback control to precisely position the transducer over the center of the desired track and to keep it there. The fine positioning system generally locks onto and tracks a magnetic pattern of some kind. Most of these magnetic servo schemes use a portion of the recording surface for a magnetic servo pattern. This obviously reduces the amount of recording surface available for the recording of data. Accordingly, non-magnetic servo schemes have been proposed, which have the obvious advantage that the servo pattern will not reduce the amount of magnetic

surface area available for storage of data. A scheme such as this which uses an optical servo for controlling the transducer position is described in US-A-3,426,337. Unfortunately, the servo pattern in this scheme must be aligned with the disk center. This requirement significantly increases the cost of achieving optical servo control of a magnetic disk transducer and has virtually foreclosed such servo control in the flexible disk field.

This invention seeks to provide an improved servo pattern for a record disk transducer control system.

The invention provides a record disk bearing a servo pattern of detectable marks so disposed that when the disk is rotated past a device for sensing the marks, there is a plurality of nested (eg substantially concentric) paths along which the rate of sensing the marks is individual to each path whereby it is possible to define a record track on the disk by reference to a selected one of the paths.

How the invention can be carried out will now be described by way of example, with reference to the accompanying drawings, in which:-

Fig. 1 schematically illustrates a known transducer control system for a magnetic record disk apparatus;

Fig. 2 schematically illustrates an optical servo control system for a magnetic record disk apparatus, which embodies the invention;

Fig. 3 is a highly magnified partial view of a uniform pattern which may be used by the optical servo system of Fig. 2 to define, locate and follow concentric magnetic tracks;

Fig. 4 is a highly magnified partial view of a non-uniform pattern which may be used in practising the invention;

Figs. 5.1 and 5.2 illustrate alternative record disk structures having a servo pattern in accordance with the invention;

Fig. 6 illustrat s a typical signal obtained from an optical sensor positioned above a non-uniform pattern on a spinning record disk;

Fig. 7 illustrates a typical processed signal obtained by filtering, thresholding and clipping a detected signal of the type shown in Fig. 6;

Fig. 8 is a plan view of concentric magnetic record tracks defined by the servo system of Fig. 2 using a uniform servo pattern; and

Fig. 9 is a plan view of non-circular magnetic record tracks defined by the servo system of Fig. 2 when the servo pattern comprises a non-uniform array of marks.

Fig. 1 schematically illustrates a magnetic record disk 10 and a typical prior art position control system for an associated transducer 12. Concentric magnetic tracks 30 on the disk are divided angularly into many equal sectors so that the position of stored information can be referenced to a particular sector beginning. Tachometer 14 supplies a signal from which the sectors are both defined and identified. A timing wheel 16 keyed to disk 10 carries timing marks 18 (which may or may not correspond one for one with sectors), as well as a distinguishable sync mark 20. The marks 18 and 20 are sensed by a suitable detector 22 (such as an optical detector, for example), which produces a signal on line 24. Counter 28 counts marks 18 and is reset by sync mark detector 26 each time it senses the signal waveform corresponding to the sync mark 20. As a result, the output of counter 28 is a discrete representation of the angular position of the disk 10 and directly or indirectly identifies the sector under transducer 12. The sector identifying information is received by a disk controller 34 via line 32.

A data source or data utilization device, such as a processor 36, originates a data transfer operation via lines 38 to disk controller 34. Disk controller 34 identifies on line 40 the track desired (T_D) for the

next data transfer operation. The current track (T_C) under the transducer 12 is identified on line 42 by a track counter 44. Both the desired track T_D and the current track T_C are typically digital numbers. Comparator 46 inspects T_D and T_C and indicates via line 48 whether a coarse movement of transducer 12 is needed, the direction of such movement, and possibly the size of the required move. A position control system 50 responds to comparator 46 and via digital-to-analog converter 52 drives a linear actuator 54 connected to transducer 12 so as to bring transducer 12 over the desired track. A tracking error detector 56 ordinarily senses whether transducer 12 is centered over a track and indicates the amount of tracking error on line 58 to the position control system 50, which drives actuator 54 so as to reduce the tracking error and keep the transducer 12 centered over the track. When a coarse move is needed (to a different track), control system 50 disregards the tracking error. Track counter 44, however, typically senses from the tracking error signal the passage of the transducer over each track and keeps count of the track currently under the transducer (T_C). Comparator 46 senses when T_C is equal to T_D and so indicates to the position control system 50. After T_C is equal to T_D, the control system 50 again responds to the tracking error signal from detector 56 and locks the transducer position onto the center of the track. Once the transducer is sufficiently close to the center of the desired track, an ON TRACK indication is given by the control system to the disk controller via line 62.

The tracking error detector responds to magnetically recorded information on the disk 10, which is extracted from the signal output line 60 connected directly to transducer 12. Various ways are known in the art for sensing or deriving tracking error information either directly from auxiliary prerecorded magnetic patterns or indirectly from the magnetically recorded data track itself. Since the exact method used for extracting the tracking information from the magnetic transducer 12 signal is not significant to the present description, a detailed description of such techniques will not be presented. The magnetic transducer signal on line 60 is also received by the disk

controller 34 so that r corded information on the desired track can be read and transferred to processor 36 and so that information from processor 36 can be recorded on the desired track via controller 34.

Each track typically has a prerecorded header containing among other information a digital identification of the track itself. The track identification is read (either by the processor or the disk controller) to verify that the desired track is the track currently being accessed. If the track header indicates that the accessed track is not the desired track, even though the control system has given an ON TRACK indication via line 62, an error has occurred. Some known systems re-initiate the track seeking procedure again in the hope that the same error will not reoccur. Others have a way of updating or correcting the track counter via a line 64 so that the T_C indicated by the track counter matches the actual track (T_A) read from the track. In such systems the change in T_C is sensed by comparator 46, which results in movement of the transducer 12 to the correct track T_D.

Fig. 2 schematically illustrates in a fashion similar to the Fig. 1 representation a magnetic record disk 66 and an associated transducer position control system, embodying the invention. Magnetic storage tracks 68 on disk 66 are defined in position and shape by an optically detectable reference pattern 70 in cooperation with the illustrated transducer position control system (hereinafter usually referred to as the servo control system). Pattern 70 is a dense two dimensional array of optically detectable marks (or spots) covering at least the whole portion of the disk surface which will at any time pass through the detection area of a sensor 72 mounted for common movement with the transducer 12. Only a portion of the pattern 70 is shown in Fig. 2. The servo pattern 70 does not interfere with or use any of the recording capacity of the magnetic record medium on disk 66. Sensor 72 responds to the spots or marks (hereinafter referred to simply as spots) and produces a waveform having many amplitude changes. The amplitude changes or transitions are counted to derive a rate at which transitions or amplitude changes are occurring within the sensed region. While it

is not necessary for the array of spots to be uniformly distributed over the sensing region of the disk and the derived rate is not necessarily equal to the rate at which spots are passing through the region monitored by the sensor, it is easier to understand the overall operation of the system if these assumptions are made initially.

The rate at which marks are passing under the sensor is proportional to the product of the linear velocity of the disk under the sensor and the density of the marks in the detection region. If the rate being derived from the sensor signal is equal to the rate at which spots are passing through the region monitored by the sensor and the spots are everywhere uniformly distributed over the surface of the disk, then the derived rate is proportional to the radius at which the monitored region is located! Each discrete magnetic record track is characterized by a discrete mark sensing rate and is defined as lying along the path which has that mark sensing rate along the entire path. If the spots are uniformly distributed and sufficiently small and numerous, the tracks will be substantially circular with their centres at the centre of the spindle (the center of the disk). The transducer position control system does not lock onto a track which is physically defined on the disk (either magnetically or otherwise), but instead seeks the particular mark sensing rate characterizing the desired track and follows whatever path is required to keep the mark sensing rate equal to that particular mark sensing rate. Since each track is defined as having the path which the control system will follow in keeping the mark sensing rate equal to a particular value characterizing that track, the control system will by definition follow the required path when it keeps the mark sensing rate equal to that particular value!

Two examples of patterns which may be used in the system of Fig. 2 are shown highly magnified in Figs. 3 and 4. In Fig. 3, the pattern of marks is an array of identical round spots arranged in regular rows and columns with each spot equally spaced from its row and column neighbors. This is an example of a perfectly uniform pattern of marks. As will become more apparent as the detailed description proceeds, it is

advantageous to have some measure of uniformity to the pattern. However, it is not necessary that the pattern be composed of marks or spots which are all identical to each other in shape or size or that the marks be equally spaced from each other. Fig. 4 illustrates a random pattern of irregularly shaped, sized and positioned spots, which is an example of a non-uniform pattern of marks useful in practising the invention. While a uniform pattern tends to define magnetic tracks which are more perfectly circular, it is not necessary that the tracks be circular. Non-uniform patterns also may be used and in fact may be easier and cheaper to form on a record disk.

As will become more apparent, the pattern is translationally invariant in that it may be shifted in any direction with respect to the centre of the disk without detrimentally affecting the operation of the system. This is very advantageous because as a consequence the pattern can be applied to a disk before the spindle hole is formed. No alignment of the pattern is required with respect to the disk. The pattern can be applied to disk material even before the disk is cut from the material.

As previously mentioned, the mark sensor 72 is mounted for common movement with transducer 12. While it is not necessary that sensor 72 be physically attached to transducer 12 as shown, the system does assume that the transducer remains always in the same relative radial position with respect to the sensor 72. In the preferred embodiment, the reference pattern is an optically detectable pattern and the mark sensor is an optical sensor. Other sensors and corresponding patterns could be used instead so long as the mark pattern does not interfere with the operation of transducer 12. For example, a capacitive sensor or an acoustic sensor could be used to detect a topological pattern. While it is preferred that the reference pattern will be imprinted and sensed using a method different from the method used to store and retrieve information from the track defined by reference to the pattern, this is not essential. It is possible for the reference pattern to be buried in the disk away from the information storage layer (or the other way

around), or for the reference pattern to be on the other side of the disk remote from the information storage layer, so long as each can be separately sensed without interfering with the other.

Figs. 5.1 and 5.2 illustrate alternative constructions for disk 66 in cross-section. A magnetic recording layer 74 and a reference pattern of reflective marks 78 are both carried by a substrate 76. In Fig. 5.1, the reference pattern is on top of the magnetic recording layer. The substrate might be made of aluminum, for example, with a magnetic record layer of ferrite and reflective marks of aluminum. In Fig. 5.2, the reference pattern is under the magnetic record layer. Conventional magnetic record layers of ferrite, for example, are so thin that they are virtually transparent at many optical wavelengths. The substrate in Fig. 5.2 might be formed of mylar, for example, and carry an aluminum pattern and a ferrite record layer. Fig. 5.1 illustrates a typical hard disk embodiment while Fig. 5.2 illustrates a typical flexible disk embodiment. Figs 5.1 and 5.2 also illustrate the magnetic transducer 12 flying above the disk 66 and the optical sensor 72 attached to the magnetic transducer.

The optical sensor 72 is shown as having separate light emitting and light detecting parts 80, 82 for illustration, but any suitable kind of detector structure could be used instead.

In Figs. 3 and 4, a sensing region 84 shown by a broken circle is superposed on the mark pattern to indicate the approximate relative size of a mark 78 with respect to the optical sensing region. As previously explained, what is desired is a measurement of the rate at which transitions or amplitude changes are occurring in the sensor signal, which may or may not be directly related to the absolute rate at which spots are passing through the sensing region. Accordingly, the relative size of the sensing region with respect to the mark size (or average mark size) is varied in practice until an optimum detector signal is obtained. It should be understood that with the aid of appropriate signal processing, an optimum detector signal might be achieved with

either a significantly larger or a significantly smaller relative sensing region.

Since the recording tracks are located and followed by a servo system which relies only upon a rate signal (the mark sensing rate) and the absolute magnitude of this rate signal varies proportionally with the speed of rotation of the disk, either the speed of rotation of the disk must be very accurately controlled or it must be measured and used to correct or compensate the measured mark sensing rate. In general accurate control of the disk speed would require sensing or measurement of the disk speed anyway. Accordingly, it is preferred that the measured disk speed be used directly to compensate the measured mark sensing rate. Referring again to Fig. 2, a tachometer 14 is shown which operates in much the same way as the tachometer 14 shown in Fig. 1 and described in detail in connection therewith. Similar reference numbers are used to identify corresponding parts in Figs 1 and 2. A reference frequency f_1 is derived from the tachometer signal on line 24 by passing the signal through a phase lock loop 86 to remove the tachometer sync mark waveform detected by the sync mark detector 26. Sector identifying information is derived and sent to disk controller 34 via line 32 as previously described in connection with the system of Fig. 1.

The mark sensing rate is represented in Fig. 2 as an instantaneous frequency f_2 received by a frequency counter 88 directly from sensor 72. It should be understood that certain signal conditioning or processing functions may or may not be performed on the raw sensor signal before it actually reaches frequency counter 88 as illustrated. Certain mark patterns, such as a uniform pattern of identical round spots, probably do not require any special processing or conditioning before reaching the frequency counter 88. The frequency counter itself automatically applies the equivalent of a thresholding and clipping function anyway.

A typical raw sensor signal from a non-uniform pattern is illustrated in Fig. 6. It contains many changes in amplitude from which a pulse train may be extracted by applying suitable signal processing such as frequency filtering, thresholding and clipping. Fig. 7

illustrates a typical pulse train which might be derived from a sensor signal. The pulses occur at typically irregularly spaced times and are characteristic of and determined by the pattern of spots. While no precise correlation is required between the derived pulses and the actual passage of individual spots through the sensing region, it is necessary that the rate at which pulses are derived from the pattern gradually increases as the radial position of the sensor increases. This tends to occur automatically because the velocity of the spots relative to the sensed region (and therefore ordinarily also the number of spots passing through the sensed region per unit time) gradually increases with radial position, assuming of course that large variations in average mark density do not occur so suddenly that the effect of the increasing linear speed of the disk with radial position is counteracted thereby.

Frequency counter 88 produces a digital output signal R_A representing the ratio between f_1 and f_2. R_A thus is a relative measure of the actual radial position of the sensor. R_A increases with radial distance from the centre of the disk in the same manner that the mark sensing rate increases with radial distance from the centre of the disk. If the pattern is uniform and the mark sensing rate increases linearly with radial distance from the centre of the disk, R_A also linearly increases with that radial distance. R_A has already been scaled by the actual speed of rotation of the disk.

As in the prior art system of Fig. 1, a data source or data utilization device, such as a processor 36, originates a data transfer operation via lines 38 to disk controller 34. Disk controller 34 identifies on line 40 the track desired (T_D) for the next data transfer operation. The desired track T_D is typically a digital number from which the corresponding characteristic radius of the desired track R_D must be obtained (represented as a particular mark sensing rate) . This conversion is a simple one for one transformation, which is conveniently done in practice by using a look up table 90. This conversion may be and probably will be done by the same processor which implements other functions such as the disk controller functions. For illustration,

various functions are shown as separate blocks when in practice many of the functions would be implemented with a single processor suitably programmed to perform these functions.

The actual radial position of the sensor R_A is then compared with the desired radial position of the sensor R_D by a comparator 92. The difference or error is sent to a position control system 94 which drives linear actuator 54 via A/D converter 52 so as to reduce the error. When the error reported by comparator 92 is sufficiently small that the transducer is on the desired recording track, an ON TRACK indication is reported to disk controller 34 so that data then can be written into or read from the desired track by the disk controller. The servo system just described moves the sensor to a radial position such that the mark sensing rate becomes equal to the characteristic mark sensing rate for the desired track and keeps adjusting the radial position of the sensor so as to maintain that characteristic mark sensing rate.

Fig. 8 illustrates the characteristic recording track pattern which will occur when the mark pattern is such that the mark sensing rate linearly increases with the radial distance of the sensor from the centre of the disk. Each of the recording tracks 68 is substantially circular with its centre at the centre of the disk or spindle. Fig. 9 illustrates instead a typical recording track pattern which might occur when the mark pattern is not uniform. Each track in general follows a noncircular path and does not cross or get too close to any neighboring track. The noncircular paths result as the servo system follows whatever path results in the mark sensing rate being held at the desired constant value. It should be apparent that the mark pattern preferably should be substantially uniform so as to not require that the servo system follow a track with excessive radial variation and to ensure that the adjacent tracks do not get too close together. Use of a mark pattern with a large degree of nonuniformity probably would result in a need to space the recording tracks farther apart (an increased difference between successive characteristic mark sensing rates). This would be disadvantageous because it would lower the recording track density.

CLAIMS

1. A record disk (66) bearing a servo pattern (70) of detectable marks so disposed that when the disk is rotated past a device (72) for sensing the marks, there is a plurality of nested (eg substantially concentric) paths along which the rate of sensing the marks is individual to each path whereby it is possible to define a record track (68) on the disk by reference to a selected one of the paths.

2. A record disk as claimed in claim 1, in which the record disk is a magnetic record disk.

3. A record disk as claimed in claim 1 or claim 2, which is flexible.

4. A record disk as claimed in claim 1 or claim 2, which is rigid.

5. A record disk as claimed in any preceding claim, in which the servo pattern is coextensive with the recording surface of the disk.

6. A record disk as claimed in any preceding claim, in which the marks are detectable optically.

7. A record disk as claimed in claim 6, in which the servo pattern is a pattern of reflective spots.

8. A record disk as claimed in claim 7, in which the reflective spots are circular.

9. A record disk as claimed in any preceding claim, in which the servo pattern is a uniform pattern of substantially identical marks.

10. A record disk as claimed in any of claims 1 to 8, in which the servo pattern is a non-uniform pattern of marks which are not identical to each other.

11. A record disk as claimed in claim 10, in which the servo pattern is a randomly arranged pattern of randomly shaped and sized marks.

12. A record disk as claimed in any preceding claim, in which the servo pattern is a closely spaced pattern of individually detectable spots.

13. A record disk as claimed in any preceding claim, in which the servo pattern is disposed between the record medium of the disk and a substrate.

14. A record disk as claimed in any of claims 1 to 12, in which the servo pattern is disposed on top of the record medium of the disk.

15. A record disk apparatus of the type wherein a radially positionable transducer (12) reads information from or writes information into a desired one of many individual information storage tracks on a spinning disk (66), the apparatus comprising:-

a record disk (66) as claimed in any preceding claim;

sensor means (72) mounted for common radial movement with the transducer (12), the sensor means (72) defining a mark sensing region on the disk (66), the mark sensing region moving radially with the sensor means and the transducer, and the sensor means detecting passage of the marks in the servo pattern (70) through the mark sensing region as the disk spins;

means responsive to the output of the sensor means to obtain a current mark sensing rate (f_2) corresponding to the rate at which the marks are currently passing through the mark sensing region;

means (90) defining a discrete mark sensing rate corresponding with each information storage track on the disk and for producing a desired

discrete mark sensing rate corresponding with a desired information storage track;

servo means (92, 94) responsive to the current mark sensing rate and the desired discrete mark sensing rate for continuously adjusting the radial position of the transducer and sensor means so that the current mark sensing rate becomes substantially equal to and remains substantially equal to the desired discrete mark sensing rate,

whereby the transducer follows a desired information storage track defined by a discrete mark sensing rate.

16. Apparatus as claimed in claim 15, in which the means for obtaining a current mark sensing rate further comprises means for sensing the angular velocity of the disk, the rate at which the sensor means detects passage of the marks through the sensing region being scaled by the sensed angular velocity of the disk to obtain the current mark sensing rate.

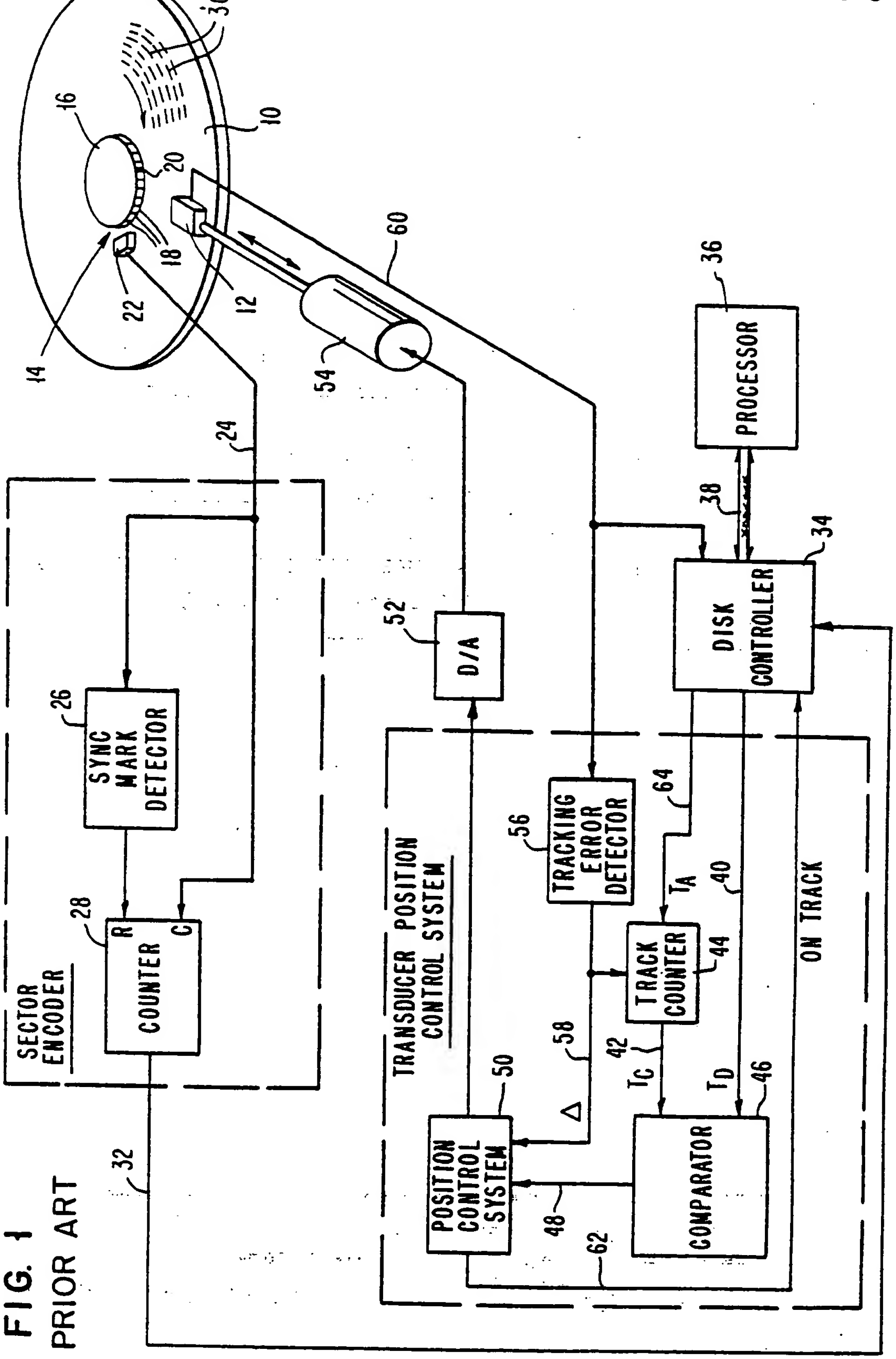
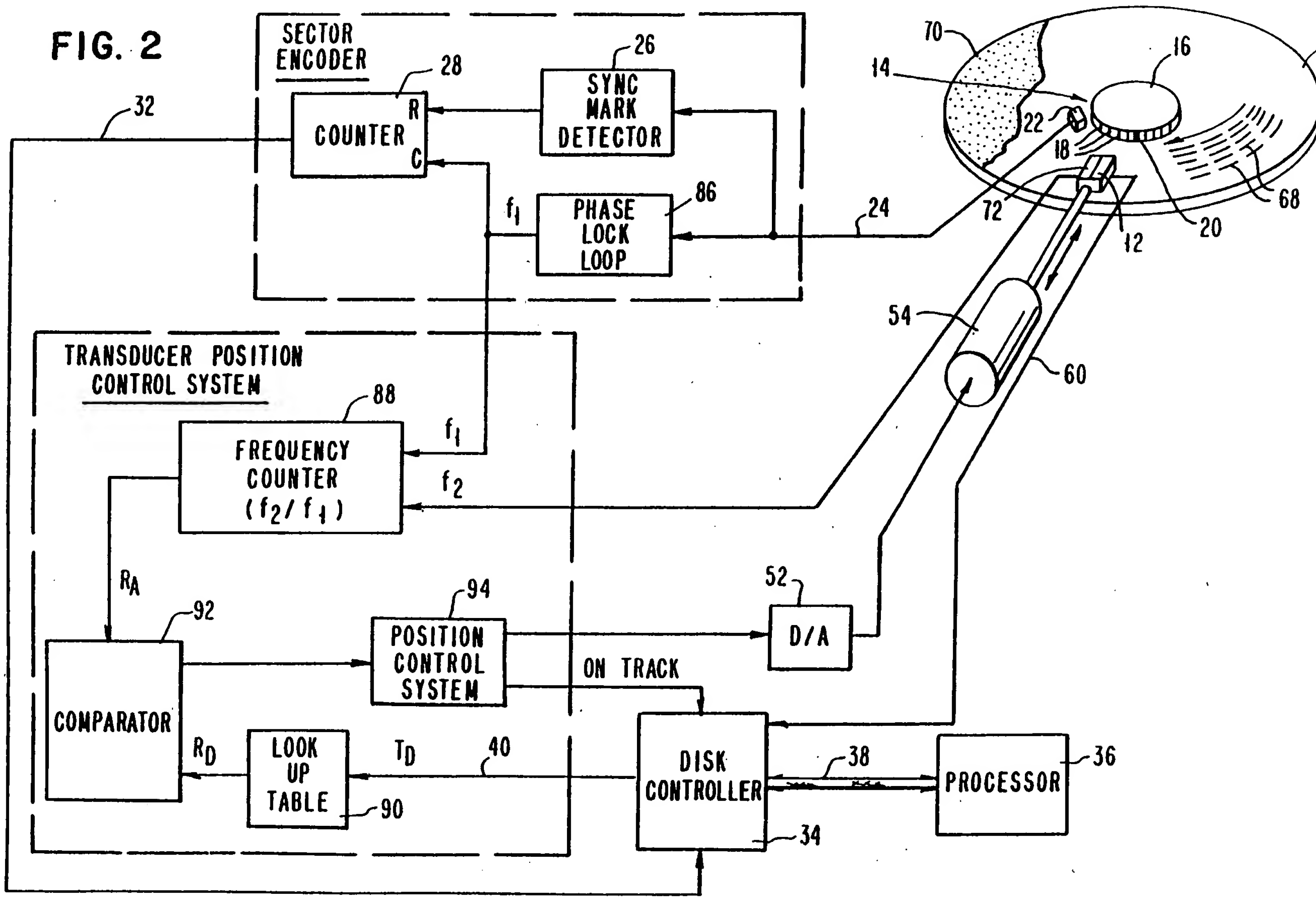


FIG. 1
PRIOR ART

FIG. 2



SECTOR ENCODER
COUNTER
R
C
SYNC MARK DETECTOR
PHASE LOCK LOOP
f_1
TRANSDUCER POSITION CONTROL SYSTEM
FREQUENCY COUNTER (f_2/f_1)
f_1
f_2
R_A
COMPARATOR
POSITION CONTROL SYSTEM
ON TRACK
D/A
LOOK UP TABLE
R_D
T_D
DISK CONTROLLER
PROCESSOR
12
14
16
18
20
22
24
26
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54
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72
86
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92
94

FIG. 3

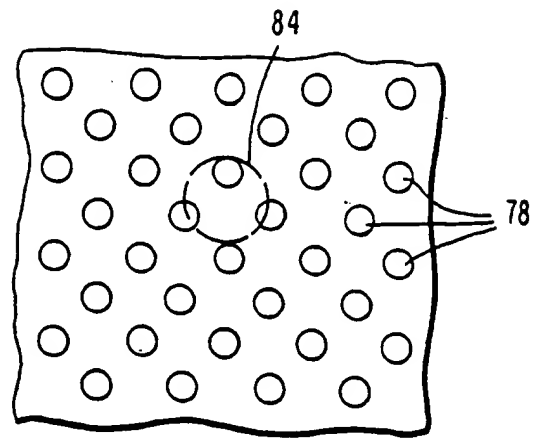


FIG. 4

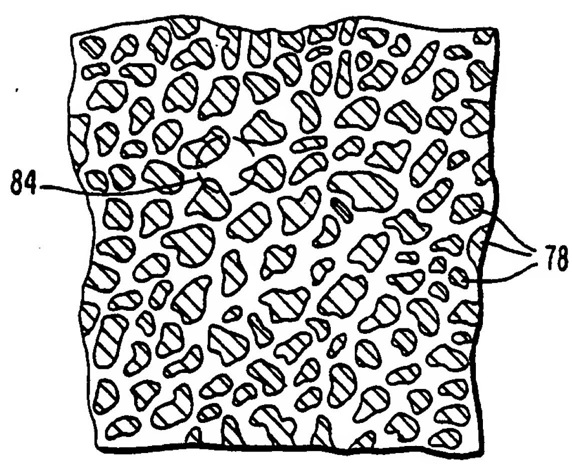


FIG. 5.1

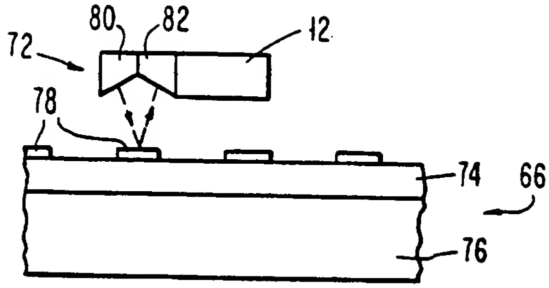


FIG. 5.2

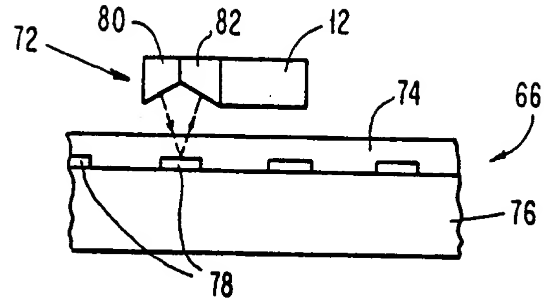


FIG. 6

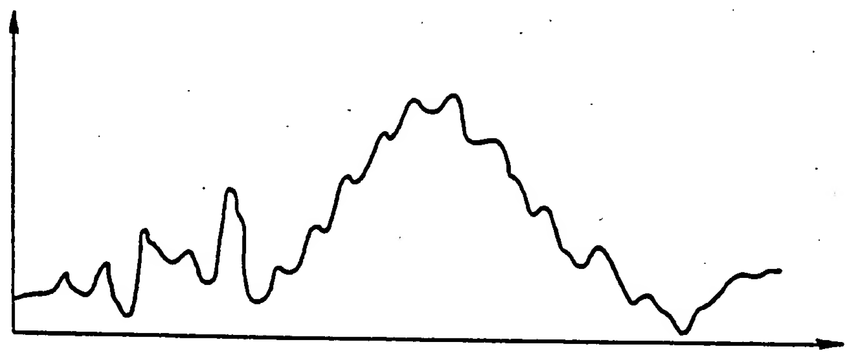


FIG. 7

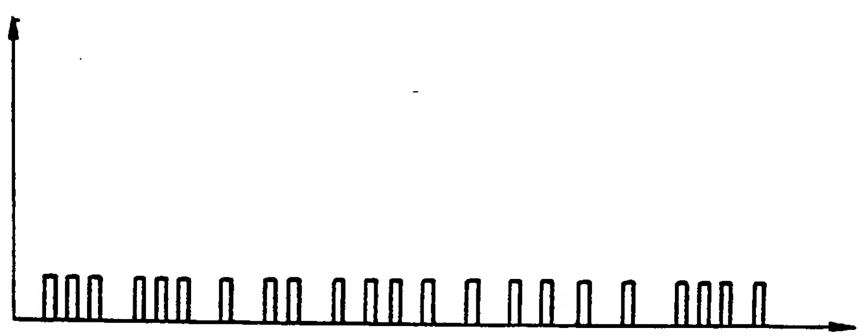


FIG. 8

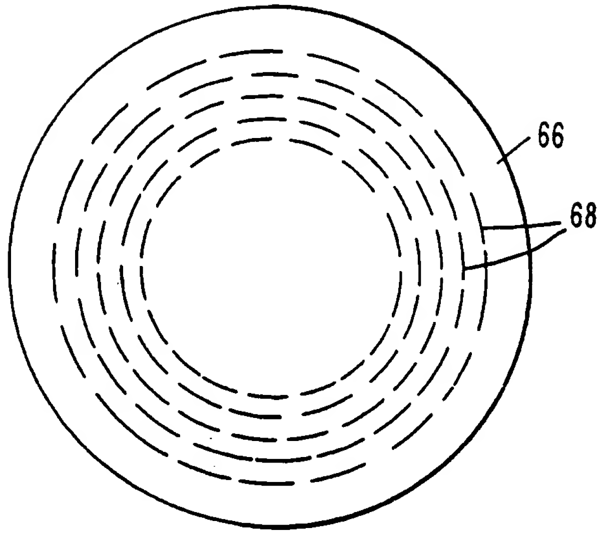
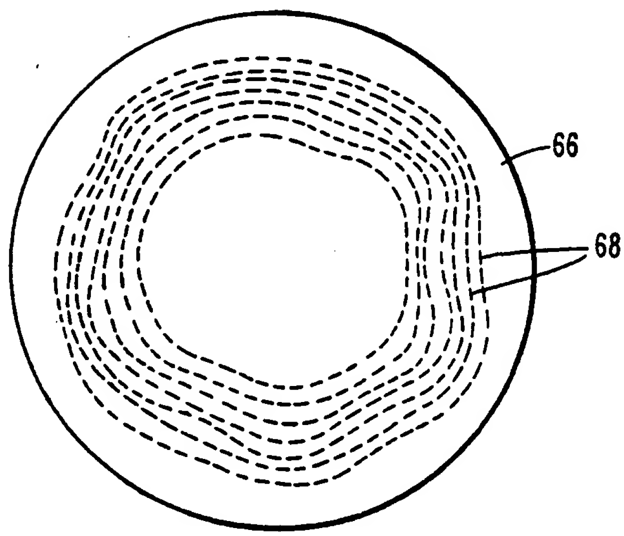


FIG. 9



European Patent Office

EUROPEAN SEARCH REPORT

0130495
Application number

EP 84107149.1

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl. 3)
X,D	US - A - 3 426 337 (BLACK) * Abstract; fig. 1-3; column 4, line 19 - column 5, line 20 * --	1,2,6,7,14	G 11 B 5/82
A	US - A - 4 326 229 (YANAGISAWA) * Fig. 1,2; abstract * --	1,2,4	
A	DE - A - 2 016 178 (BURROUGHS) * Fig. 1-3; claims 1-8 * --	1,2,4	
A	DE - A - 2 018 753 (IBM) * Fig. 1,2; claims 1-3 * ----	1,2,3	

TECHNICAL FIELDS SEARCHED (Int. Cl. 3)

G 11 B 5/00
G 11 B 17/00
G 11 B 25/00

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
VIENNA	05-10-1984	BERGER

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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P : intermediate document
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E : earlier patent document, but published on, or after the filing date
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